ATA Applied Technology Associates, Inc.

STABILIZED SENSOR PLATFORM FOR MANNED SPACE OBSERVATION

Phase I Results
SBIR AF90-140

Prepared for
Mission Planning Division
Space Test Program SSD/CLPD
Los Angeles AFB, CA

by
Applied Technology Associates, Inc.
and
Rockwell International Space Systems Division

March 6, 1991

ATA

PRESENTATION PLAN

- Introduction
- Review of Project Plan and Technical Objectives
- Tasks 1 & 2 Results - System Requirements
- Task 3 Results - Stabilization Technology Concept
- Task 4 Results - SSPMSO Design & Verification
- Summary of Findings, Critical Questions, and Recommendations

91B0280 2

INTRODUCTION

- Purpose and Objective
- Problem Overview
- Key Thrusts
- SDIO/AF Starlab Replan

PURPOSE AND OBJECTIVE

- **Purpose:**
  - Present and Discuss the Phase I Findings, Results, and Recommendations

- **Objective:**
  - Establish Basis for Positive Decision on Proceeding Forward with Phase II
  - Create Foundation for Phase II Program Plan

PROBLEM OVERVIEW

- Man's Active Participation in Space Observation Experiments is Enhanced by:
  - High Magnification
  - Means to Capture Observations
  - Accurately Pointed and Stabilized Line-of-Sight

- Flexible, Effective Technology to Provide the Latter is the Primary Goal of This SBIR Project

- ATA/Rockwell Team Asserts That
  - Stabilization is Feasible by Integrating Several Innovative Components: Dynalens, MHD Inertial Angular Motion Sensor, and DSP-Based Digital Electronics
  - A Manual Gimbal Enhances Operations

KEY THRUSTS

- Understand Full Requirements Set for Crew Cabin Experiment Equipment
  - Performance
  - Operations
  - User Interactions

- Identify/Select Stabilization Concept That Addresses Performance Requirements

- Plan and Prioritize Phase II to Achieve Development an Demonstration of Critical Technology for SSPMSO

STARLAB REPLAN

- ATA/Rockwell Envisioned a First SSPMSO Flight with Starlab, But
  - SDIO Directed That Starlab *as* STS Mission Required Change
  - SDIO's ATP Experiment is Now a Freeflyer
- Joint SSPMSO/Starlab Experiment No Longer Valid Plan

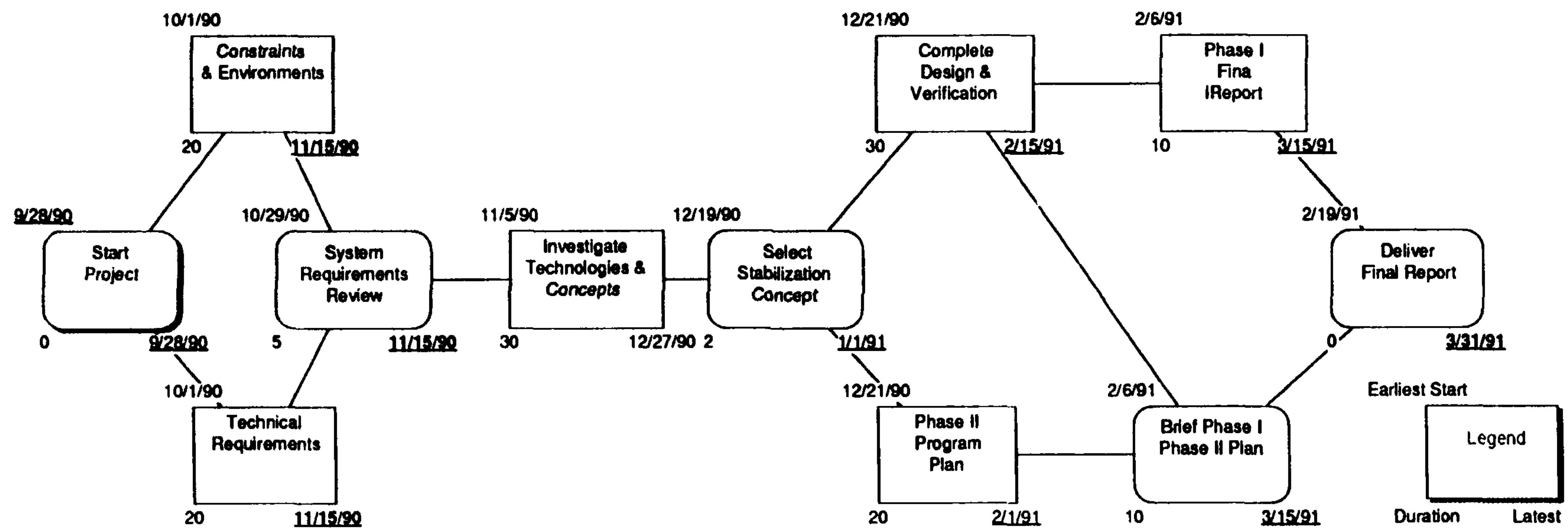
ATA

REVIEW OF PROJECT PLAN
TECHNICAL OBJECTIVES - PHASE I

- Identify and Document Technical Performance and Operational Requirements
- Identify and Interpret Design Constraints and Environments Which Must Be Recognized
- Select Technology/Configuration Which Fulfills Requirements Within Constraints
- Complete Design Documentation and Breadboard Validations
- Prepare/Present Phase II Plan to Accomplish On-Orbit Demonstration of Prototype
- Document Phase I Results

ATA

REVIEW OF PROJECT PLAN AND TASKS AND SCHEDULE - PHASE I



91B0280 9

ATA

TASK 1 AND 2 RESULTS - SYSTEM REQUIREMENTS

- Overview of Task 1 and Task 2 Approaches
- SSPMSO System Requirements Document
- Critical Requirements/Priorities
- Discussion of Selected Critical Requirements

OVERVIEW OF APPROACH

- Baseline Typical STS Manned Observation Mission Parameters
- Baseline Typical Optical Payload
- Identify STS Crew Cabin Experiment Constraints and Environments
- Collect Information, Review, and Understand Implications
- Compile List of Requirements

ATA

SSPMSO SYSTEM REQUIREMENTS DOCUMENT

1) Field of Regard of the Two Gimbal Axes
2) Accuracy of Gimbal Pointing
3) Allowable Residual Jitter of the Stabilized Line-of-Sight (LOS)
4) Slew Rate to Maintain the LOS on a Viewed Object
5) Range of Attached Optical Payload Mass Properties and Size Envelopes
6) Search and Acquisition Time to Center on Desired Object
7) Attachment Method for Optical Payload
8) User Interface Features
9) STS Interfaces
10) Optical Characteristics of Elements (If Any) Placed in the Viewing Path
11) Electrical Power
12) Environment
13) Thermal
14) Safety
15) Flammability, Odor, and Offgassing
16) Materials
17) Conducted and Radiated EMI Emissions
18) Electrical Isolation and Bonding
19) On-Orbit Setup, Temporary Stowage, and Stowage
20) Checkout and Operations

1) SBIR Problem Description, AF90-140
2) Quick Response Shuttle Payload for Department of Defense Space Test Program
3) Shuttle Orbiter/Cargo Standard Interfaces, ICD-2-19002
4) Shuttle/Payload Interface Definition Document for Middeck Accommodations, NSTS 21000 IDD MDK
5) Summary of DOD Secondary Payload Optical Systems for SSPMSO Study
6) Overhead Window Mounting Techniques
7) Proposal for the Design, Fabrication and Test of a 12-Inch Dynalens
8) Proposal for the Design and Fabrication of IMAX Image Motion Stabilizer
9) Optical V/H Image Motion Compensation System
10) Wideband Angular Vibration Experiment Quick-Look Reports Nos. 1 and 2
11) Beam Control System Modeling and Simulation - Interim Subtask Report for Subtask 03-06, Section 3.0 Remote Sensing System and Appendices A and B
12) Notes, Informal Communications, and Telephone Conferences
13) SDIO Space Shuttle Based Experiments for Acquisition, Tracking and Pointing (Definition of Space Shuttle Operational Environment)
14) Basic Theory of Window Degradation on an Optical System
15) Crew System Design Requirements, NASA Document XXXX
16) Payload Integration Plan, Annex 2, Flight Planning Services Black Book

ATA

BASELINE FOR STS MISSION

Parameters for Typical Orbits and Signficant to Sensor Platform Design

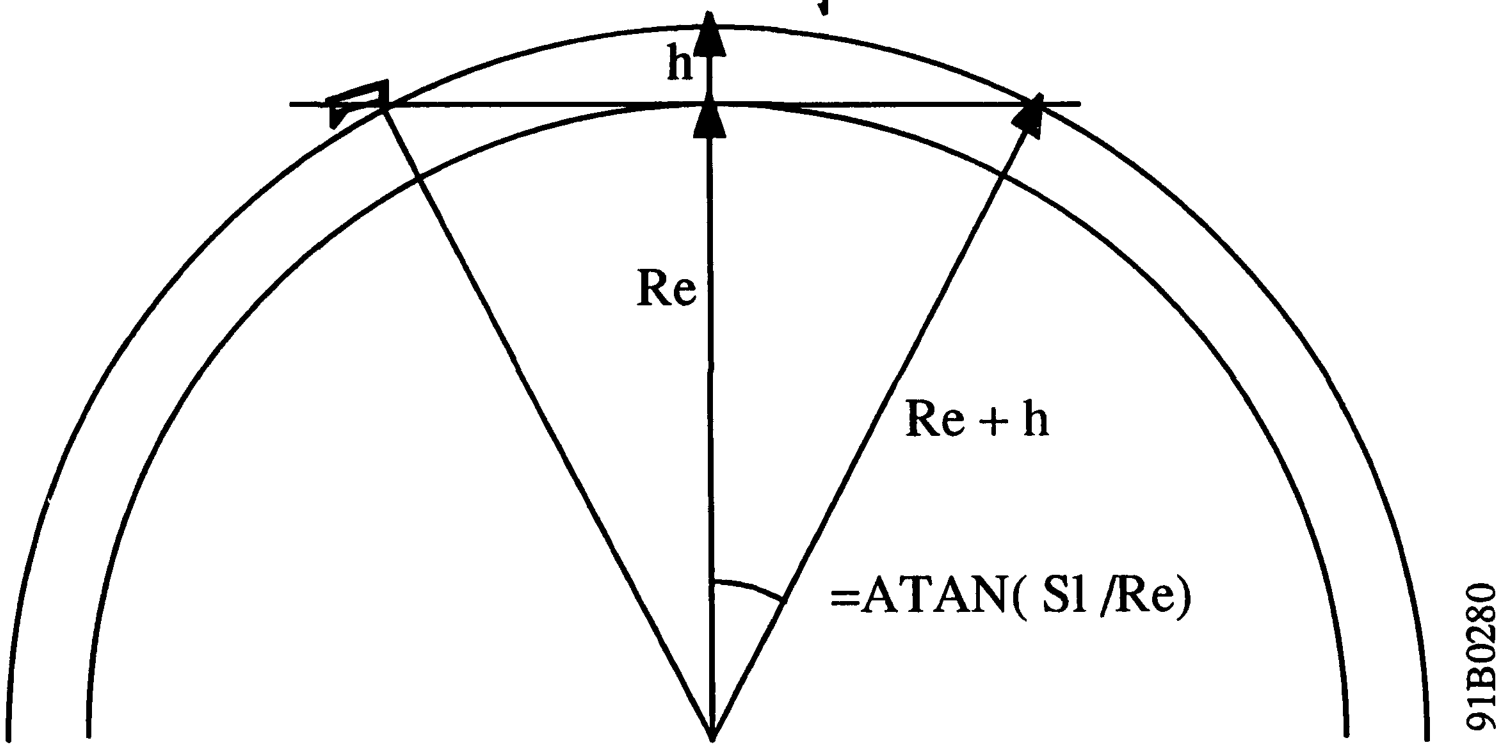
Parameter	Case 1	Case 2
Orbit Altitude (km)	259	398
(Nautical Miles)	(140)	(215)
Earth Radius (km)	6,376	6376
Orbit Radius (km)	6,636	6,774
STS Velocity (km/s)	7.75	7.67
Circular Distance (km)	41,693	42,566
Orbit Period (min)	89.6	92.5
Earth Pt Velocity (km/s)	0.46	0.46
STS to Earth Pt Ang Rate (rad/s)	0.028	0.018
Max Slant Range (STS to Earth Pt) (km)*	1,837	2,288
Viewing Half Angle(deg)*	16.1	19.7
Viewing Time (min)*	8.0	10.1

*The range of viewing angles from the orbiter to the earth target is influenced by atmospheric obfuscation. The tangential distance is an upper bound at which target search can be started. Considering the time to locate the target and the degradation caused by atmosphere, the maximum high quality viewing time is 4 minuites less than the listed values.

9 ID0280 14

BASELINE OPTICAL PAYLOAD

SL = √(Re + h)**2 - (Re)**2



Geometrical Relations for Calculating Viewing Parameters

BASELINE OPTICAL PAYLOAD

- **Large Magnification Telescope**

- Aperture	8" (203 mm)	- FOV	0.6° (10 mrad)
- Focal Length	90" (2032 mm)	- Resolution	0.57 sec (2.7 μrad)
- Focal Ratio	8/10	- Telescope Length	18.5" (470 mm)
- Std Eyepiece	25 mm, Kelner, 81x	- Telescope Weight	9.6 lb

- **Observation Recording Device (Camera/CCD)**

	Dimensions (Inches) (L x W x D)	Typical Weight (lbs)
- Camera	3 x 6 x 7	4
and/or		
- CCD	6 x 5.5 x 2.5	3.3
- Teleconverter	4 x 2.5	0.25
- Miscellaneous	6 x 2.5 (Envelope)	1.0

ATA

STABILIZATION REQUIREMENT

- Factors Which Govern Stabilization
  - Image Does Not Move Significantly in Relation to Resolution Diameter
  - 8" Aperture Case Implies Resolution of 2.7 μrad Diameter
  - Jitter (1-Axis, 1-σ) $\leq$ Resolution Radius

- Single "Snapshot" Observation Require Stabilization Only During Exposure Time Interval
  - Continuous Observation Implies "Snapshot" Stabilization Plus Subresolution Image Motion Between Observations

- SSPMSO Stabilization Goal: Jitter $\leq$ 1.0 μrad (1-axis, 1-σ), All Frequencies Above 1 Hz

POINTING ACCURACY REQUIREMENT

- Factors Which Govern
  - It Must Be Possible to Place and Hold a Viewed Object at a Location Withing the FOV, Say $\leq$10% of FOV
  - FOV of 8" Aperture Celestron is 0.6° (10 mrad)
  - Drifts of Viewed Object During Observation Interval Should Be Correctable Within Capability of Manual Actions
- SSPMSO Accuracy Goal: Position and Hold LOS Within 1 mrad of Designated Location

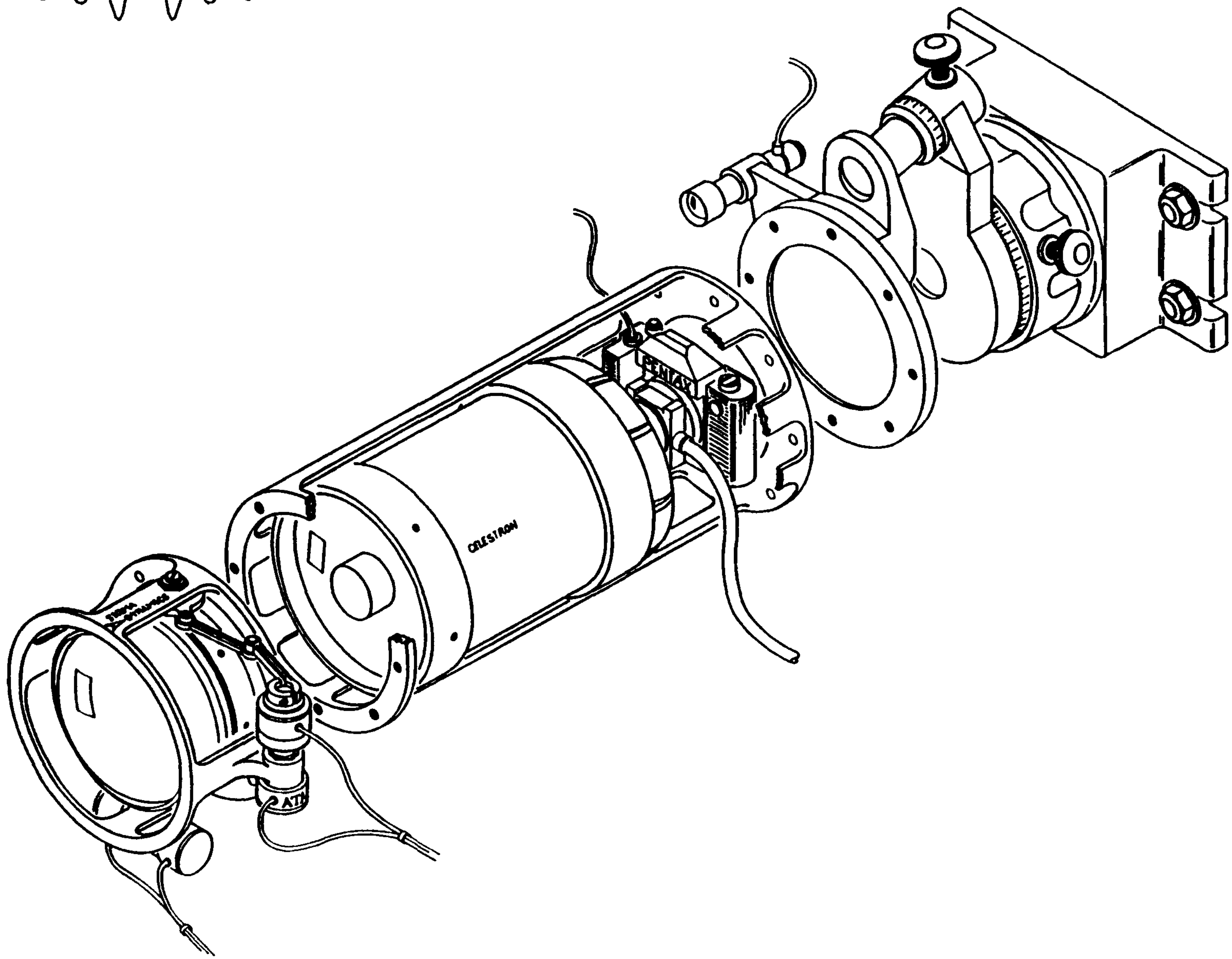
MECHANICAL CONFIGURATION

- Factors Which Govern
  - Provides Required Angular Degrees of Freedom for STS MSO Missions (>40° Along Track, >20° Cross Track)
  - Interfaces with STS Window Structures
  - Compatible with Middeck Locker Storage
  - Establishes and Maintains Alignment of Payload in Relation to Orbiter Reference System
  - Accommodates Attachment of SSPMSO Jitter Suppression and Digital Signal Processor Assemblies
  - Satisfies Applicable Requirements for Safety, Materials, and Operations
  - Low Risk to Manufacture

- Configuration Goal: Functional and Low Cost Manual Gimbal System Which Provides Upgrade Path for Future Fully Automated System

ATA

MECHANICAL CONFIGURATION



ATA

PAYLOAD FLEXIBILITY

- SSPMSO Mechanical Assembly is Modular
- Standardized Payload Carrier Facilitates Changeout of Payload/Carrier Assembly
- SSPMSO Accommodates a Suite of Several Payloads by Making Carriers with a Variety of Internal Structures and Adaptors
- Several Payloads May Be Taken to Orbit Each in an Experiment Ready Carrier Assembly

ATA

OPERATOR FRIENDLINESS

- Assembly is Simple
- Adjustments to Establish Correct Boresight Alignment
- Electronic Control of Fine Pointing and Jitter Suppression
- Video Monitor Display of Observed Images in WFOV and NFOV

ATA

TASK 3 RESULTS - STABILIZATION TECHNOLOGY CONCEPT

- Overview of LOS Stabilization/Pointing
- Control System Concepts/Technologies
- Critical Components

ATA

OVERVIEW OF LOS STABILIZATION/POINTING

- **LOS Pointing and Stabilization System Definition**

  "electro-mechanical assembly that is capable of rejecting and responding to effects of environments, target maneuvers, and host vehicle maneuvers and disturbances so that the payload LOS is maintained on the target with sufficient accuracy and without jitter."

- **Pointing and LOS Stabilization Controls are Separate Functions**
  - **Stabilzation Control Isolates Payload from Host Vehicle Operational Disturbance**
  - **Pointing Control Established LOS of Payload**
    - **By Measuring Target Location in Tracking Sensor FOV, or**
    - **By Measuring Payload Orientation Relative to Host Vehicle**

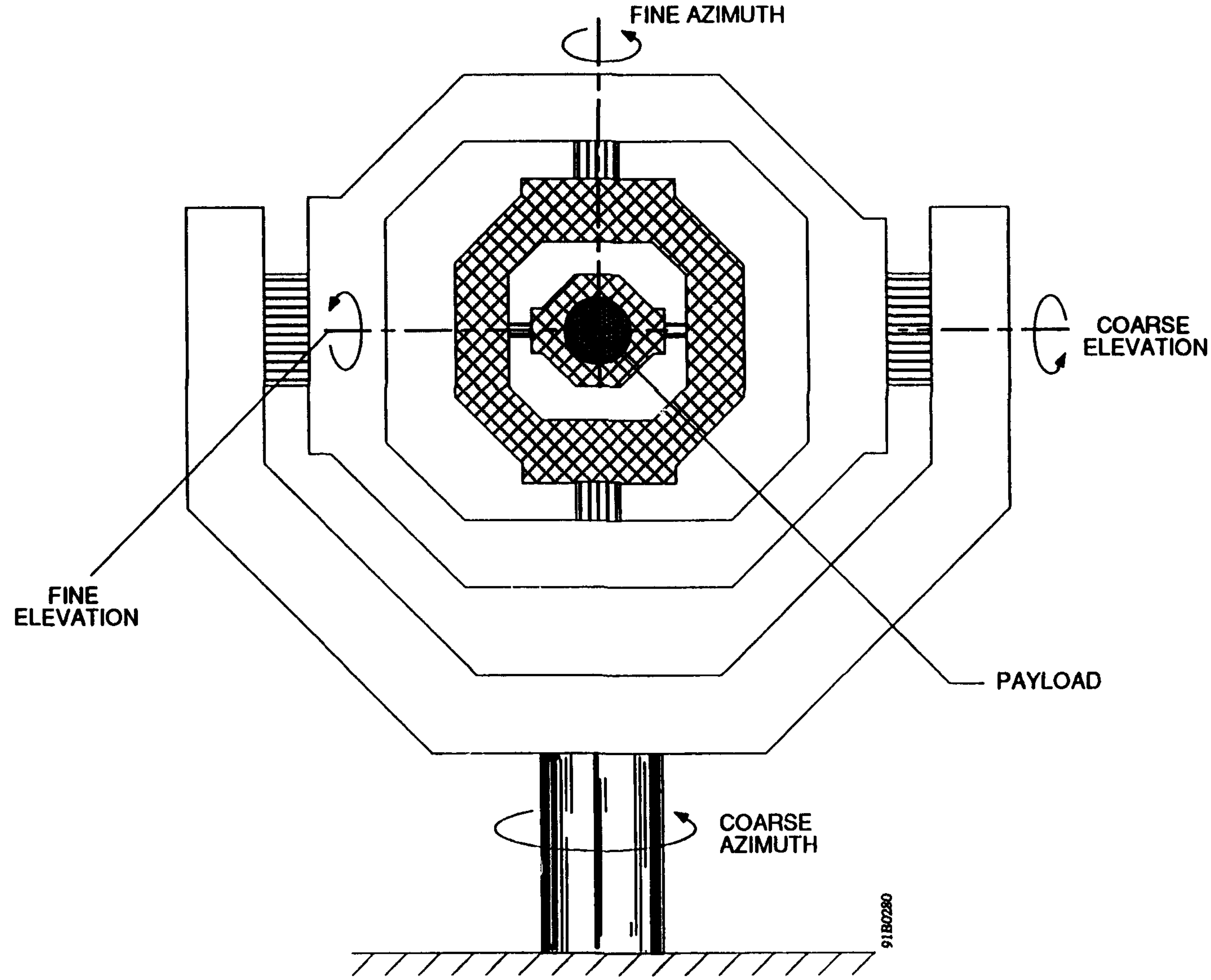
OVERVIEW OF LOS STABILIZATION/POINTING (cont)

- Several Technolgies Have Been Developed for Precision* Stabilization and Pointing
  - Nested Gimbals Systems Use a "Fine" Gimbal to Carry Payload and a "Coarse"Gimbal to Carry Fine Gimbal
  - Fast Steering Mirror (FSM) Assemblies are Used to Correct for LOS Pointing/Stabilization Errors by Adjusting LOS Relative to the LOS of Coarse Gimbal LOS Reflected on FSM
  - Dynalens Works to Correct LOS Direction (Like FSM), But is Transmissive in Contrast to Reflective
- Angle Range of Precision Elements are Limited and Must Be Configured With "Coarse" Pointing Assembly

* Order of Microradians or Less

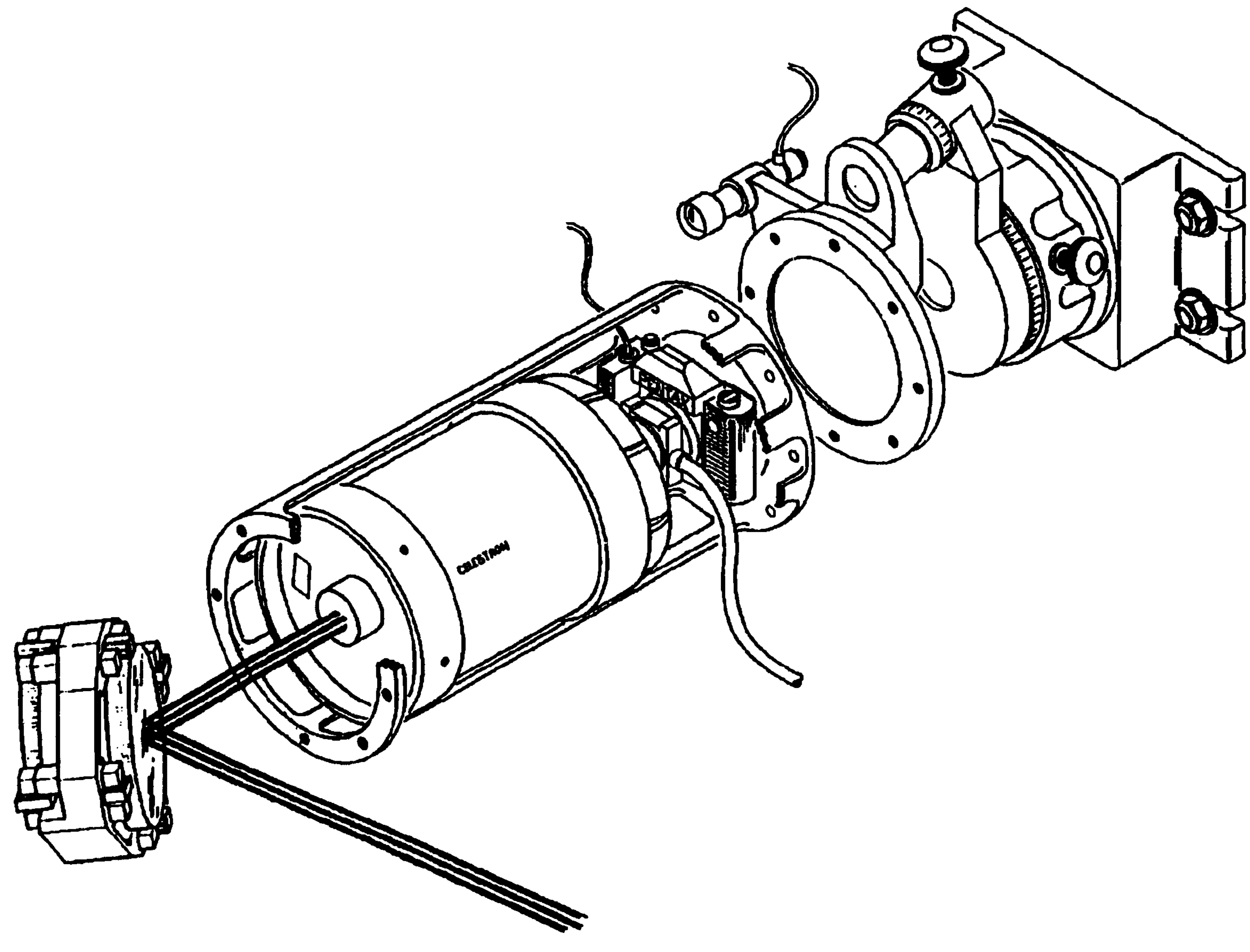
ATA

NESTED GIMBAL ASSEMBLY

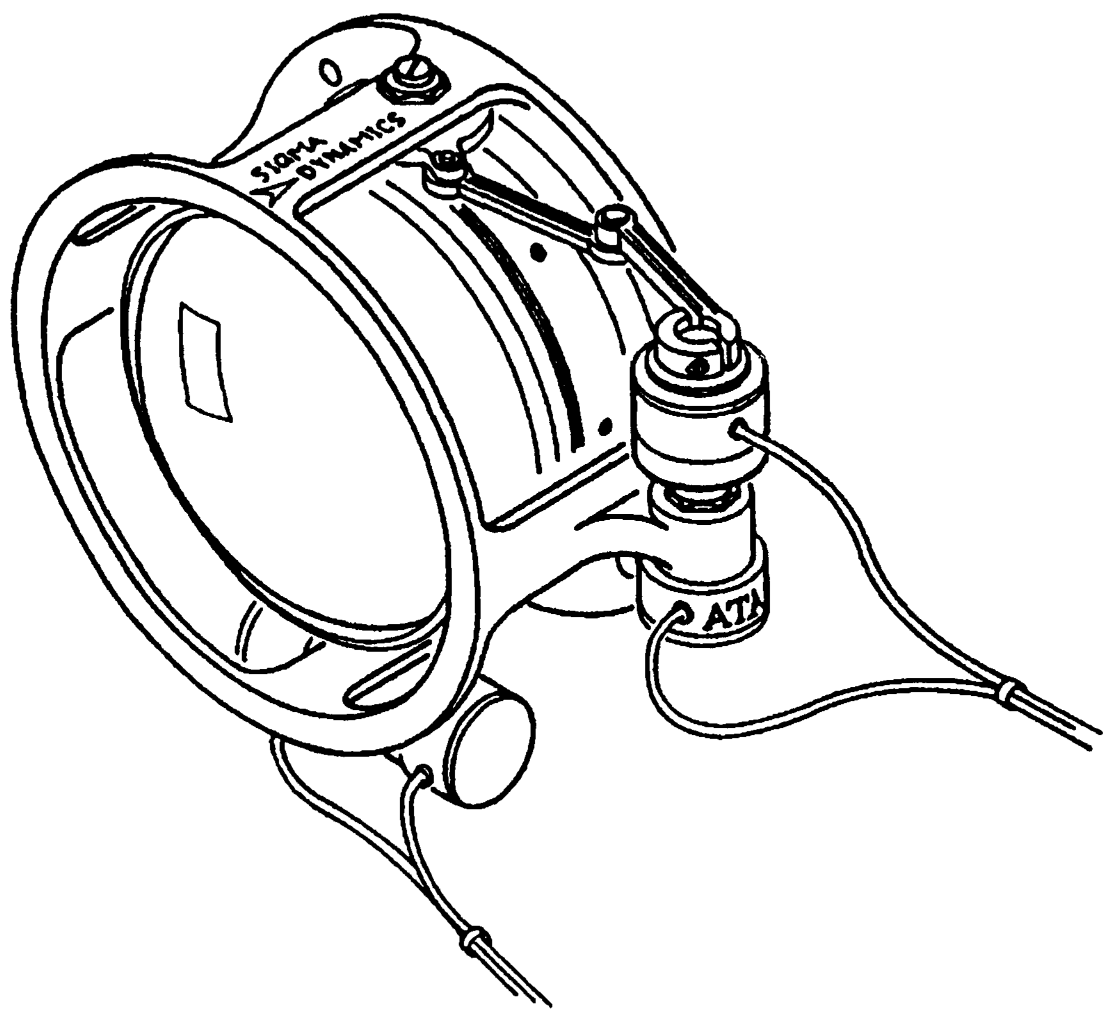


ATA

FAST STEERING MIRROR CONFIGURATION



DYNALENS



OVERVIEW OF LOS STABILIZATION/POINTING (cont)

- **Disturbance Which Influences LOS STAB/PTC Performance Include:**
  - **Host Vehicle Vibrations (Angular and Linear) and the Coupling of These Disturbances to the LOS - Bearing/Support Design Schemes Try to Minimze the Coupling**
  - **Measurement Noise of the Control Loop Sensors**
  - **Control System Electronics Noise**
  - **Noise of Actuators to Move Payload**

CONTROL SYSTEM CONCEPTS/TECHNOLOGIES

- Classical Servo Loops
- Disturbance Cancellation Enhancements
- Adaptive Disturbance Cancellation Schemes

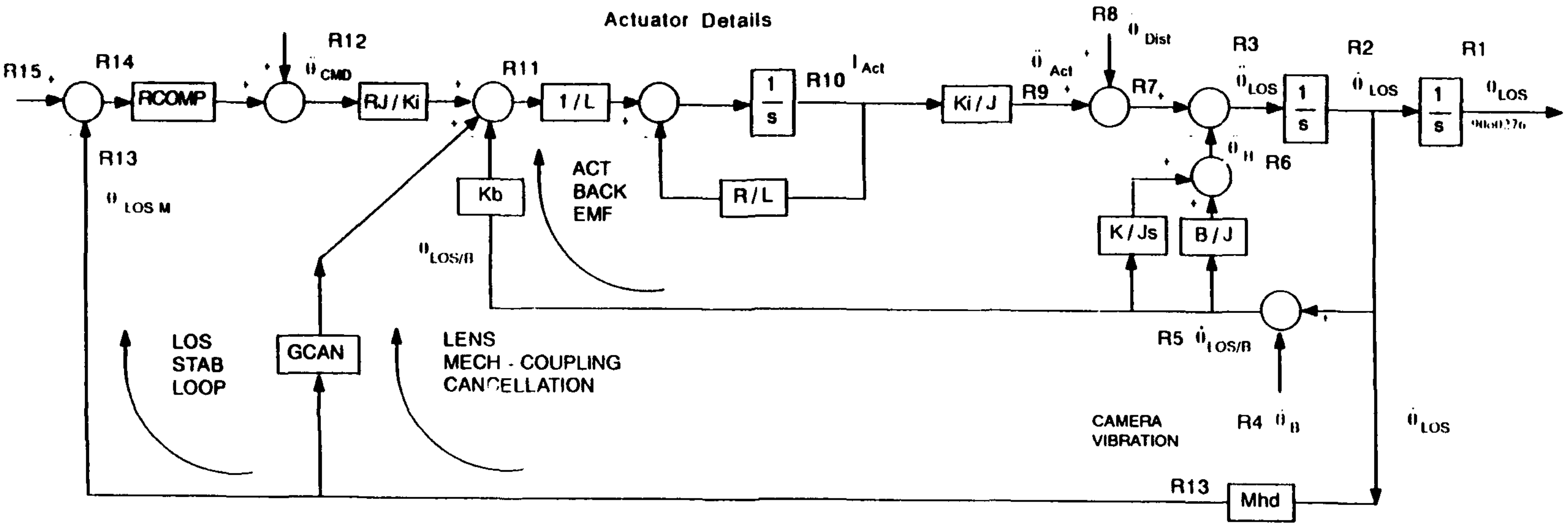
ATA

CLASSICAL SERVO LOOPS

- Purpose: Keep Measured Errors Near Zero
- Stabilization Control Loop
  - Employs Inertial Sensor to Measure Payload Jitter
    - Rate Gyros Measure Angular Rate of Payload
    - Rate Integrating Gyros Measure Angular Position
  - Commands Acutators to Hold Payload Against Disturbances
  - Responds to Commands from the Pointing Loop
  - Sensor Quality, Disturbance Spectra, and Loop Design Establish Performance
  - Low Noise Gyros are Expensive
- Pointing Control Loop
  - Employs Tracking Sensor or Angle Encoder to Measure Pointing Errors
  - Generates Commands Which Cause Changes in Payload Pointing
  - Very Precise Pointing Requires High Cost Sensors
  - Pointing Loop Bandwidth Needs to Be Compatible with Relative Kinematics of Target LOS - Typically Much Less Than Stabilization Loop

ATA

CLASSICAL LOS SERVO LOOP



PARAMETER	SIMULATION	VALUE	DESCRIPTION
R	P1	1.0	Resistance of Actuator Coil, Ohm
J	P2	1.0	Inertia of Controlled Element, oz-in-sec**2
Ki	P3	1.0	Actuator Torque Coeficient, oz-in/amp
L	P4	0.001	Inductance of Actuator Coil, Henries
Kb	P5	0.0	Back Emf Coeficiation, V/rad/s
B	P6	31.459	Coeficient of Viscous Torque Coupling, oz-in/rad/s
K	P7	24,742	Spring Coeficient, oz-in/rad
Kr	P8	350	Stabilization Loop Gain Parameter, volt/volt
N1	P9	0.159	Stab Loop Comp Numerator Coef
D1	P10	0.159	Stab Loop Comp Denominator Coef
D0	P11	0.0	Stab Loop Comp Denomination Coef
Wc	P12	31.42	Naturnal Frequency For Load After Tuning, rad/sec
Zc	P13	0.707	Damping Ratio for Load After Tuning
Mn2	P14	0.0072	Mhd Sensor Model - Numerator s**2 Coef, volt/rad/s
Md4	P15	1.5125E-12	Mhd Sensor Model - Denominator s**4 Coef
Md3	P16	1.2513E-8	Mhd Sensor Model - Denominator s**3 Coef
Md2	P17	5.0100E-5	Mhd Sensor Model - Denominstor s**2 Coef
Md1	P18	4.0163E-4	Mhd Sensor Model - Denominator s**1 Coef
Md0	P19	7.7285E-4	Mhd Sensor Model - Denominator s**0 Coef

RATE LOOP COMPENSATION

$$RCOMP = \frac{Kr\,(1.0 + N1\,s)}{D0 + D1\,s}$$

MECHANICAL COUPLING CANCELLATION

$$GCAN = Kc\,[\,(K - \hat{K})/s + (B - \hat{B})\,]$$

where

$Kc = (R/Ki) / Mhd$

$\hat{K} = J\,Wc^{**}2$

$\hat{B} = 2\,J\,Zc\,Wc$

91B0280 32

DISTURBANCE CANCELLATION

- Purpose: Sense Disturbances and Keep LOS from Responding (Resulting in Non-Zero Errors)

- Identify That Part of the System Output Which is Coherent with the Disturbance

- Apply Appropriate Signal to Actuator So That It Responds to Cancel Effects of Disturbance

- Disturbance Cancellation is an Enhancement to Classical Servo Loop

- Typically is Employed in "Open Loop Feed Forward" Implementation Such That Corrective Commands are Injected into a Classical Servo Loop from Outside the Loop

- Requires Accurate Measurement of Disturbances and Scaling of Commands

ADAPTIVE DISTURBANCE CANCELLATION

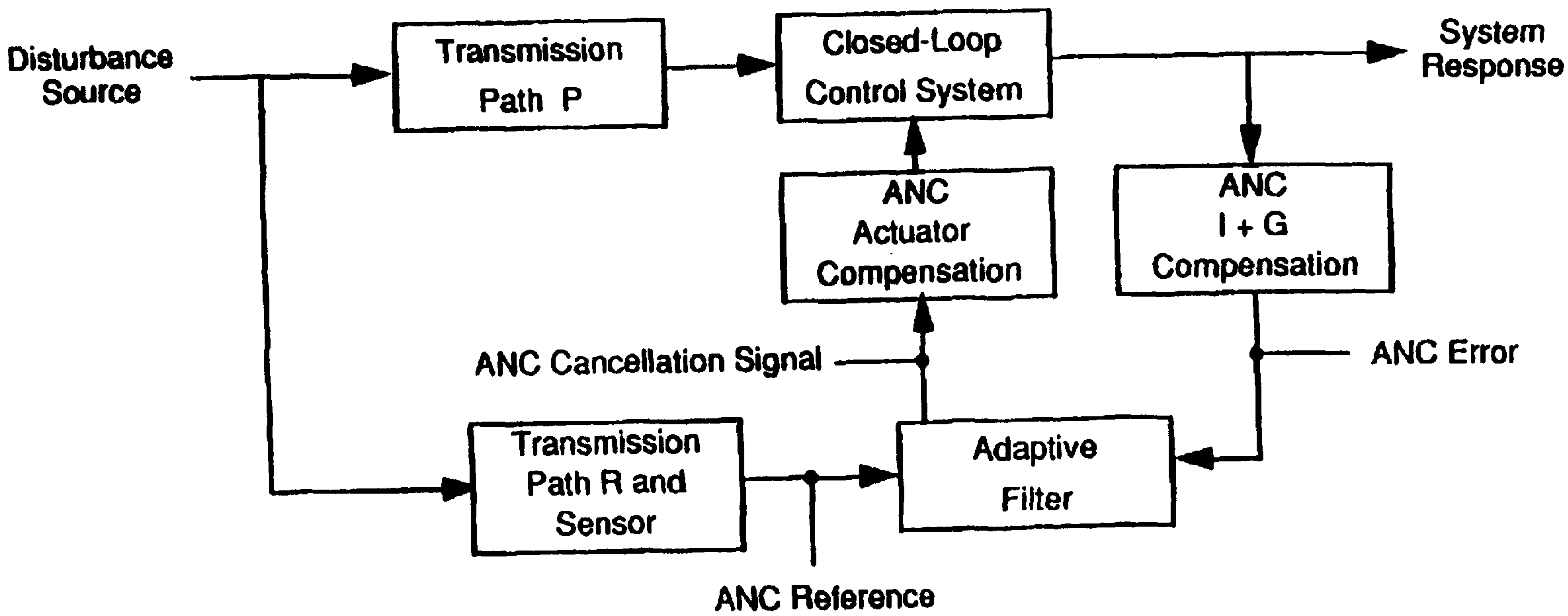
- Purpose: Sense Disturbnaces and LOS Stabilization and Pointing Errors; Apply Cancellation Signals to Actuators Which Are Computed to "Minimize" Correlation Between Residual Errors and Sensed Disturbances

- Disturbances Cancellation Signals are Proportional to Disturbance Measurements But the Gain and Phase Relations are Continuously Adjusted (Adapted)

- Implementation of Adaptive Process is With Digital Processor Hardware and Software

ATA

ANC CONSTRUCT FOR CLOSED-LOOP CONTROL SYSTEMS



- Adaptive Filter is Same as ANC Signal Processing Filters
- Single Disturbance Case Studied in Earlier Work

ATA

CRITICAL PRECISION POINTING SYSTEM COMPONENTS

- Inertial Angular Motion Sensor
- Relative Angle Sensor
- Actuators and Devices for LOS Adjustment
- Gimbal Assembly
- DSP/Computer System

INERTIAL ANGULAR MOTION SENSORS

- Senses Angular Motion of Payload
- Sensor's Angle Noise Equivalent Governs Performance of LOS Stabilization
- Sensor Quality as Indicated by Drift Rate and Angle Noise Equivalent are Reflected in Cost
- A Variety of Sensor Principles and Vendors From Which To Choose
- Gyros Respond to Constant Rate Motion (DC-Response)
- ATA's MHD and Systron Donner's IAS Have 1 - 2 Hz Low Frequency Cutoff

ATA

INERTIAL ANGULAR MOTION SENSORS (cont)

- Gyros
  - Phillips Lab and ATA Tested 8 Gyros From 7 Vendors
  - Candidates Were Compatible with Precision Pointing and Stabilization Requirements (< 1μrad Noise)
  - Technologies Included Floated Gyros, Dynamically Tuned Gyros, and Ring Laser Gyros
  - Vendors Who Supplied Gyros Included Draper Lab, Singer Kearfott, Teledyne, Bendix, Ferranti, Litton, and Rockwell

- ATA MHD and Systron Donner IAS
  - 1 - 1,000 Hz Response Bandwidth
  - 1 μrad Angle Noise Used in RME Spacecraft Precision Pointing Experiment

ATA

RELATIVE ANGLE SENSOR

- SSPMSO Will Be Pointed Using Sensors to Measure Orientation of LOS Relative to Shuttle's Structure (Attached to STS Window)
- Accuracy of Relative Angle Sensor Influences LOS Pointing Accuracy
- Dynamic Range to Handle Full Range of Pointing Angle to Smallest Value of Pointing Angle Correction
- Optical Disk Encoder Provides Direct Digital Readout
- Resolving Potentiometer Provides Analog Output

RELATIVE ANGLE SENSOR (cont)

- For Small Angles - Linear Disp/Radius Yields Angles
- Differential Impendance Transducers (DITs) Measure Small Relative Positions
- Linear Variable Differential Transformer (LVDTs) Measure Small Relative Positions

ACTUATORS FOR LOS CHANGES

- As Noted Previously; Gimbals, Fast Steering Mirrors, and Dynalens May be Used to Point/Stabilize the LOS
- Actuators Apply Torques and/or Forces to Change LOS Direction
- Torque Motors and Linear Electromagnetic Actuators Create the Torques and Forces
- LOS Pointing/Stabilization Performance Will Be Influenced by Torque Force "Noise" of the Actuators and the Spectral Character of Noise
- Sometimes this Noise is Referred to as Force/Torque "Ripple"

ATA

EXOCENTRIC GIMBAL

- Unique Patented Gimbal Design by Tom Applebury of Rockwell
- Rotation About Center Remote From Gimbal Mechanism
- Provides Optical Geometry Advantage for Viewing Through Window
- Increased Pointing Precision - Gimbal Arms Move More than Payload
- Gimbal Stiffness Advantages Over Conventional Gimbals
- Previous Work Provides Analytical Tools to Treat Exocentric Gimbal Dynamics and Control

DIGITAL SIGNAL PROCESSORS

- Control Systems for Pointing and Stabilization May Be Implemented in Analog or Digital Electronics

- Processing Capacity of Off-the-Shelf Digital Signal Processors (DSPs) are Compatible with Requirements for SSP Pointing/Stabililzation Control Implementation

- Multi-Degree of Freedom Active Motion Control Systems Have Been Implemented at ATA
  - NASA Microgravity Isolation Test Bed
  - DARPA Vibration Isolation for X-Ray Lithography Apparatus

- DSPs Have Been Used to Implement Adaptive Disturbance Cancellation Sample Rates of 10 kHz and Up

ATA

STABILIZATION TECHNOLOGY SUMMARY

- Technology Approaches Are Available to Address Key SSPMSO Pointing and Stabilization Requirements
- Several Concepts Exist for Precision Stabilization
- Results of Several Different Experiments Will Serve As Basis for SSPMSO Design

ATA

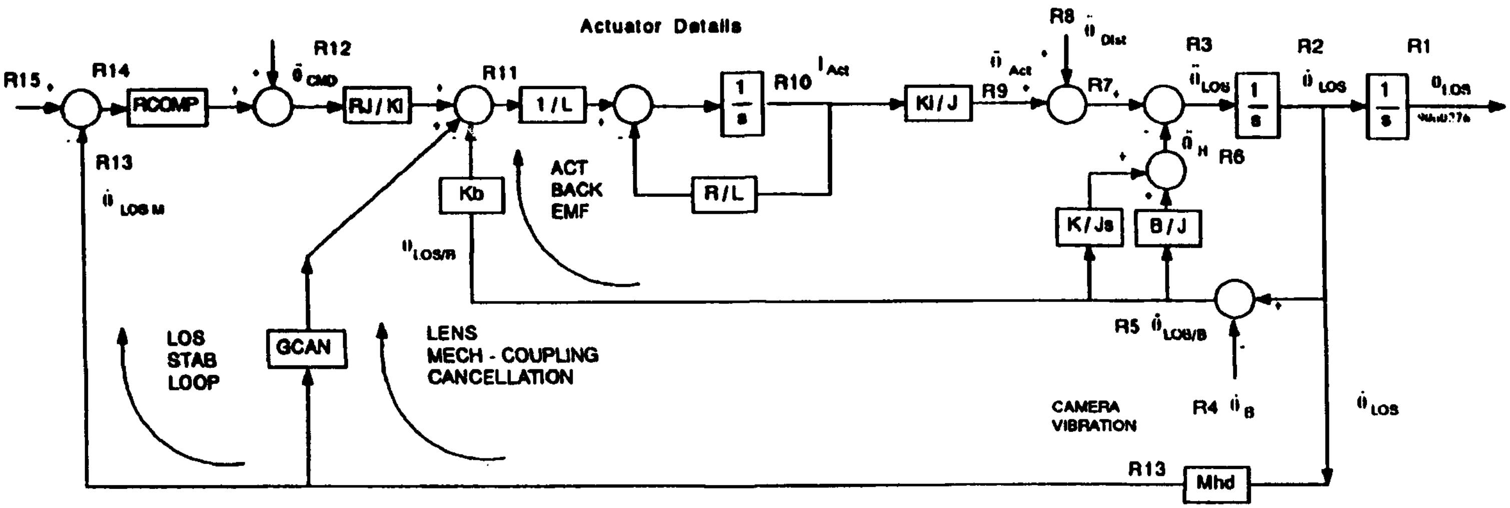
JITTER SUPPRESSION DESIGN AND REQUIREMENTS VERIFICATION

- **Approach**
  - Develop Simulation Models of Stabilization Servo (Jitter Suppression) with Dynalens and MHD
  - Confirm Reasonable Disturbance Rejection Frequency Response
  - Verify That Pointing Loop May Be Added to Stabilization Loop Without Degrading Its Performance
  - Utilize Prior Experiences with LOS Stabilization Control to Verify Credibility of Approach
    - RME
    - DAMPER
    - SSP
    - STARLAB

ATA

JITTER SUPPRESSION DESIGN AND REQUIREMENTS VERIFICATION (Cont)

- **Analysis Model**



PARAMETER	SIMULATION	VALUE	DESCRIPTION
R	P1	1.0	Resistance of Actuator Coil, Ohm
J	P2	1.0	Inertia of Controlled Element, oz-in-sec**2
KI	P3	1.0	Actuator Torque Coeficient, oz-in/amp
L	P4	0.001	Inductance of Actuator Coil, Henries
Kb	P5	0.0	Back Emf Coeficiation, V/rad/s
B	P6	31.459	Coeficient of Viscous Torque Coupling, oz-in/rad/s
K	P7	24,742	Spring Coeficient, oz-in/rad
Kr	P8	350	Stabilization Loop Gain Parameter, volt/volt
N1	P9	0.159	Stab Loop Comp Numerator Coef
D1	P10	0.159	Stab Loop Comp Denominator Coef
D0	P11	0.0	Stab Loop Comp Denomination Coef
Wc	P12	31.42	Naturnal Frequency For Load After Tuning, rad/sec
Zc	P13	0.707	Damping Ratio for Load After Tuning
Mn2	P14	0.0072	Mhd Sensor Model - Numerator s**2 Coef, volt/rad/s
Md4	P15	1.5125E-12	Mhd Sensor Model - Denominator s**4 Coef
Md3	P16	1.2513E-8	Mhd Sensor Model - Denominator s**3 Coef
Md2	P17	5.0100E-5	Mhd Sensor Model - Denominator s**2 Coef
Md1	P18	4.0163E-4	Mhd Sensor Model - Denominator s**1 Coef
Md0	P19	7.7285E-4	Mhd Sensor Model - Denominator s**0 Coef

RATE LOOP COMPENSATION

$$RCOMP = \frac{Kr\,(1.0 + N1\,s)}{D0 + D1\,s}$$

MECHANICAL COUPLING CANCELLATION

$$GCAN = Kc\,[\,(K - \hat{K})/s + (B - \hat{B})\,]$$

where

$Kc = (R/KI)\,/\,Mhd$

$\hat{K} = J\,Wc^{**}2$

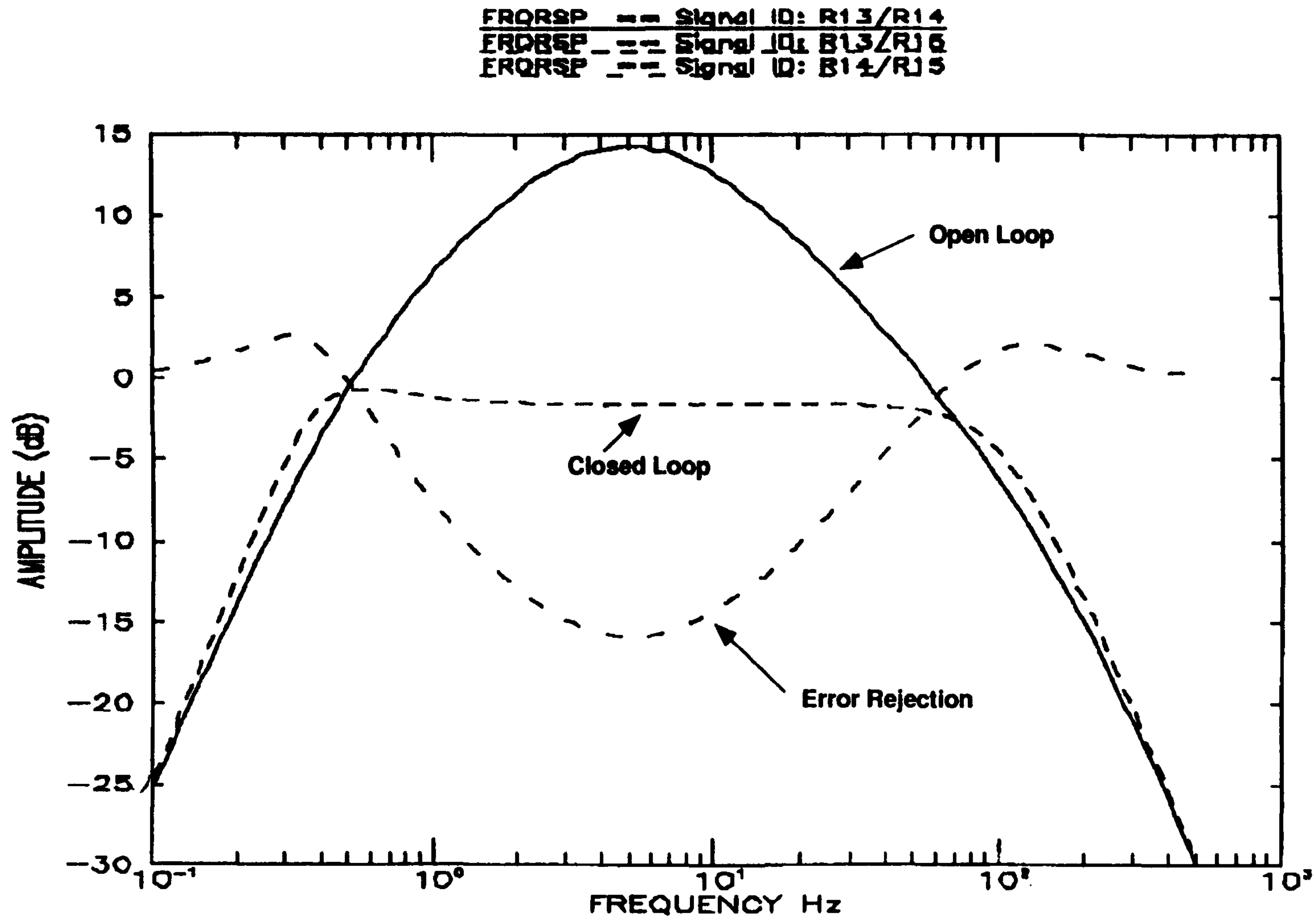
$\hat{B} = 2\,J\,Zc\,Wc$

91B0280 46

ATA

JITTER SUPPRESSION DESIGN AND REQUIREMENTS VERIFICATION (Cont)

- **Design Predictions**



91B0280 47

ATA

JITTER SUPPRESSION DESIGN AND REQUIREMENTS VERIFICATION (Cont)

- **Design Verification**
  - Dynalens and MHD Sensor May Be Used in One or More Servo Configurations to Perform LOS Stabilization to SSPMSP Requirements Level
  - Performance Achieved Will Depend on Disturbance Levels and Spectra
    - Data Describing Angular Vibration of Window Not Yet Found
    - Accurate Measurements of Disturbances Not Known
    - Existing Data Exhibits Frequency Characteristics Which Can Be Handled by Dynalens/MHD LOS Stabilization Concepts
  - Jitter Suppression Assembly Fits into Locker

ATA

GIMBAL SET DESIGN AND VERIFICATION REQUIREMENTS

- **Approach**
  - Seek Information on Existing Small Gimbals
  - Contact Vendors for Related Applications
    - Theodolites
    - Telescope Pointers
  - Evaluate/Analyze Exocentric Gimbal Concept
  - Define Design Concept to Fulfill Pointing Geometry Requirements
  - Payload Flexibility Imposed

ATA

GIMBAL SET DESIGN AND VERIFICATION REQUIREMENTS (Cont)

- Design Verification
- Manual Gimbal Design Concept Selected
- Geometry Requirements Must Be Satisfied
  - Pointing Cone of >40°
  - Two Degrees of Freedom Adequate
  - Roll Axis May Be Added Easily
- Center of Rotation at Window (or at Dynalens)
- Concepts for Attachment to Window Evaluated and Confirmed
- Gimbal Design Size is Compatible with Locker

INERTIAL SENSOR DESIGN AND REQUIREMENTS VERIFICATION

- Approach
  - Review Existing MHD Sensor Designs for Compatibility with Requirements
  - IET-1.8 Most Closely Fits
    - Safety and Space Qualification Testing Issues Addressed
    - Noise/Sensitivity Performance OK
    - Bandwidth OK
  - IET-1.8 Modified for Installation in Dynalens Stabilization Control Loop
  - Perform Laboratory Characterization of Modified MHD

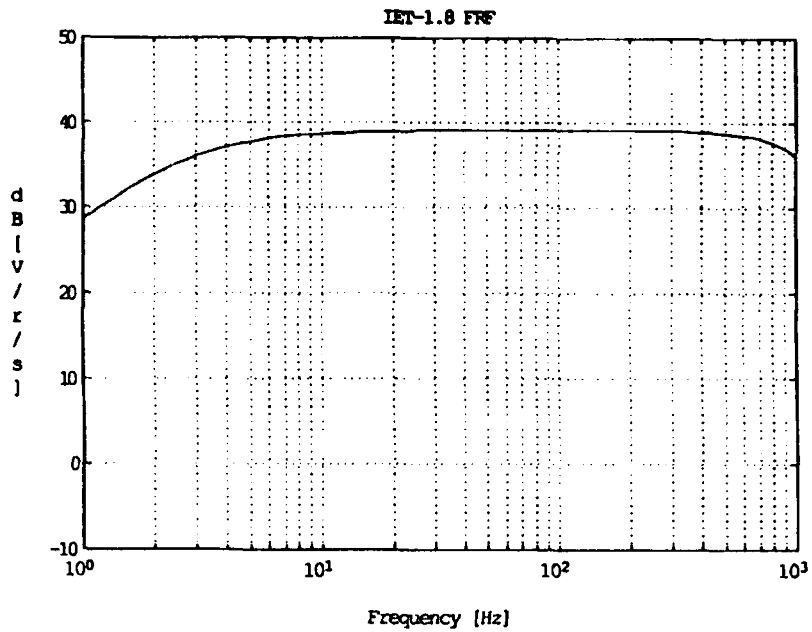
ATA

INERTIAL SENSOR DESIGN AND REQUIREMENTS VERIFICATION (Cont)

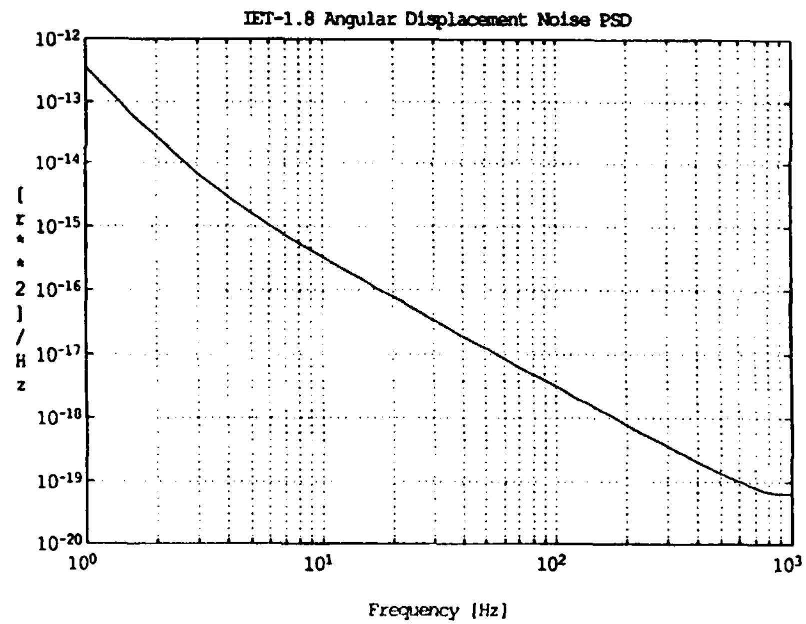
- **Requirements Verification**

Noise RMS

1 - 1000 Hz	0.37 μrad
1 - 10 Hz	0.36 μrad
10 - 100 Hz	0.05 μrad
100 - 1000 Hz	0.02 μrad



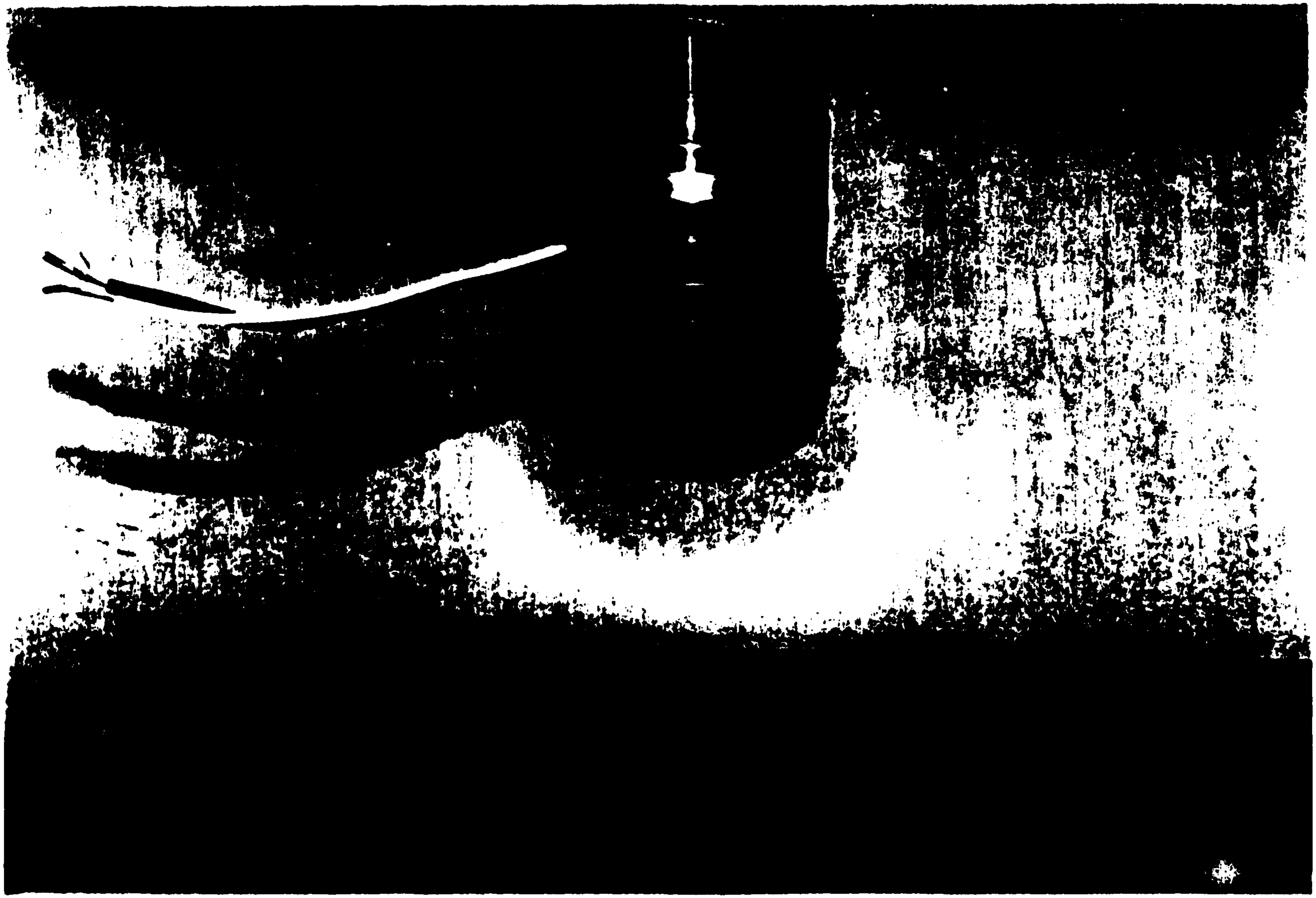
Bandwidth Spans Requirements for SSPMSO



Measurement Noise Level is Low Enough

ATA

SSPMSO-TYPE MHD SENSOR (ASSEMBLED)



ATA

SSPMSO-TYPE MHD SENSOR (EXPLODED VIEW)

ATA

DIGITAL SIGNAL PROCESSOR DESIGN AND REQUIREMENTS VERIFICATION

- Approach
  - Utilize Design Based on NASA-Funded SBIR Phase II Project (DAMPER)
  - Confirm DAMPER DSP Control System Fulfills Requirements
    - Stabilization Control Loop
    - Pointing Control Loop
  - Assess Capability for Future SSPMSO Enhancements
  - Assess Its Capability as Data Collection Element for SSPMSO Demonstration Experiment

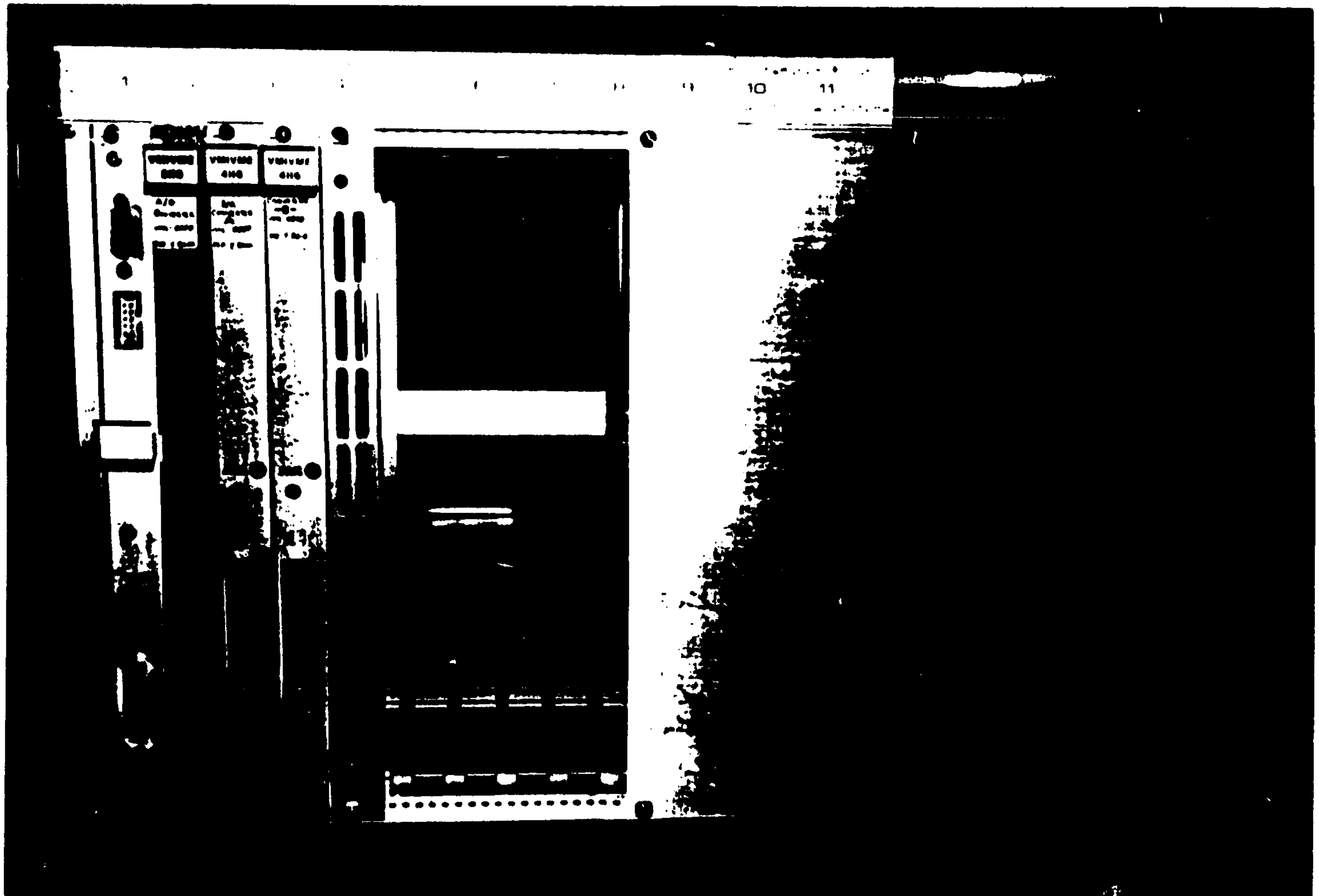
ATA

DIGITAL SIGNAL PROCESSOR DESIGN AND REQUIREMENTS VERIFICATION (Cont)

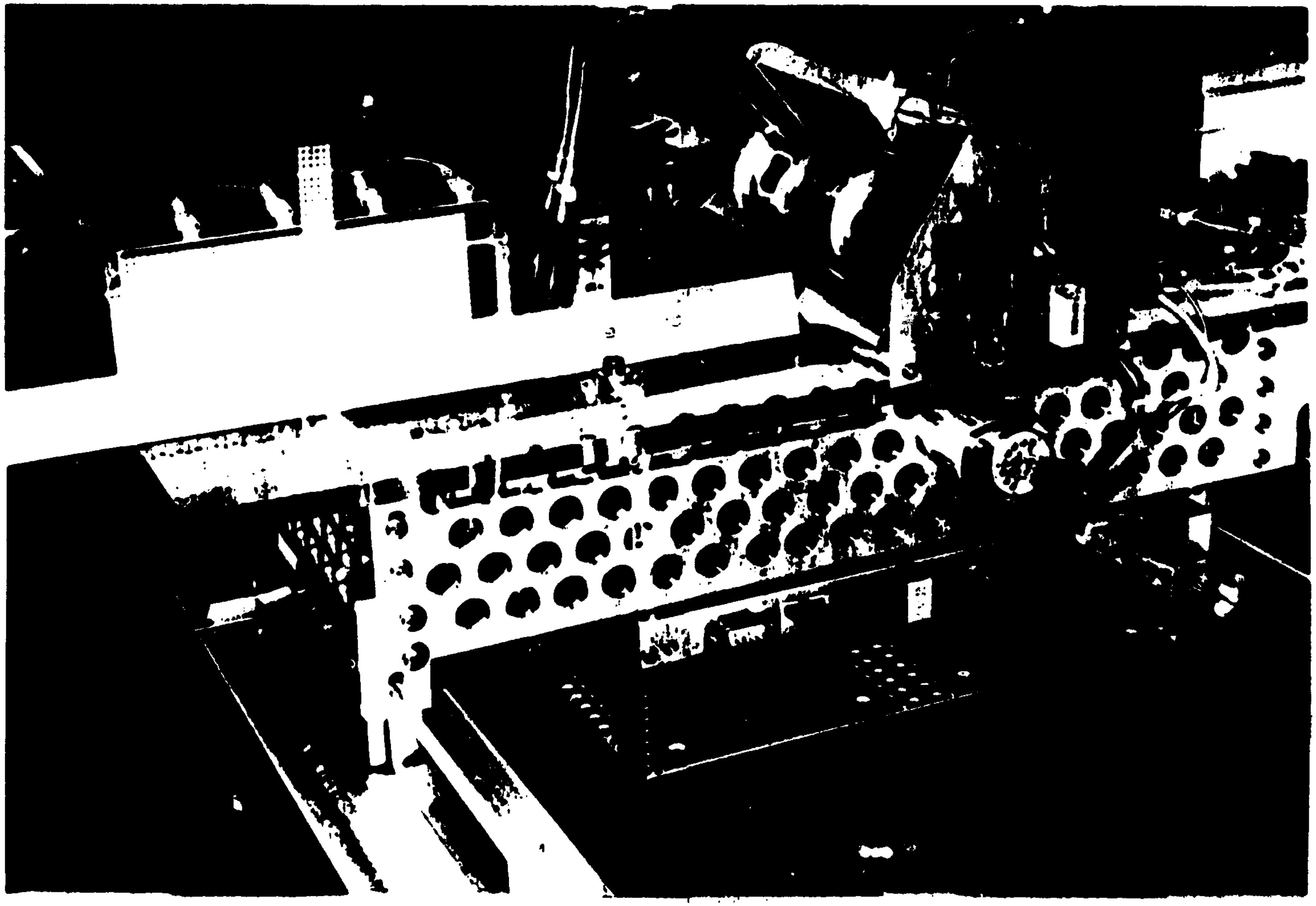
- Requirements Verification
  - SSPMSO Requirements Less Strict Than Those Imposed on DAMPER
  - Digital Processor Design Concept Fulfills Requirement
  - Flight Qualification Compatibility is TBD
  - Assembly Compatible with Locker Storage
  - Size and Weight Reasonable

ATA

DARPA-SPONSORED ISOLATION PROJECT



- **DSP Provides Lithography Apparatus Isolation**



- **NASA Phase II SBIR Implements Active Controller for Micro-g Level Isolation**

ATA

ADAPTIVE DISTURBANCE CANCELLATION DESIGN AND REQUIREMENTS VERIFICATION

- **Approach**
  - Assess RME's Adaptive Disturbance Cancellation Design Application to SSPMSO
  - Confirm Validity of Concept for SSP

ATA

ADAPTIVE DISTURBANCE CANCELLATION DESIGN AND REQUIREMENTS VERIFICATION (Cont)

- Requirements Verification
  - Experiment Implanted on RME's Satellite Tracking Equipment
  - Vibration of Mirrors in Gimbal Optics Causes LOS Jitter
  - Transducers Which Measure Vibrations Show Signals that Correlate with LOS Jitter
  - Results are Encouraging - Jitter Reduced by Factor of 4
  - RME Requirements are Similar to SSPMSO
  - Concept is Valid for LOS Jitter Suppression in SSPMSO

SUMMARY

- Key Requirements
- Design Concepts
- Critical Technical Questions
- Recommendations for Phase II

ATA

KEY REQUIREMENTS

- Pointing and Stabilization Compatible with Baseline Optical Payload
    - Pointing Accuracy < 1 mrad (0.06 deg)
    - LOS Jitter < 1.0 μrad (1σ, 1-axis)
    - Acquisition Device Has FOV > 8 deg
- Modular Design Accommodates Typical Optical Payloads
- Does Not Degrade Optical Viewing (Visible)
- Fits Mid-Deck Locker
- Compatible with Aft Deck Window Viewing Experiments
- No STS Requirements Incompatibilities
- "Friendly" to Crew

ATA

DESIGN CONCEPTS - VERIFIED

- MHD Inertial Sensor's Noise and Bandwidth
- Dynalens Optics
- Stabilization Loop Performance (Disturbances Not Very Well Known)
- Digital Signal Processor Implements Control Loops
  - MHD Sensor/Dynalens Performs LOS Stabilization
  - Dynalens with LVDT or DIT Performs Small Angle Pointing
- Adaptive Disturbance Cancellation an Option for Digital Processor
- Exocentric Gimbal Provides Pointing Angle Coverage
  - Manual Initially
  - Flight Payload Automated in Future Upgrades
- Carrier Assembly Accommodates Wide Range of Payloads

ATA

CRITICAL TECHNICAL QUESTIONS

- On-Orbit Flight Performance of Dynalens-MHD-DSP LOS Stabilization
- Operation of Equipment in STS Environment
- Disturbances to System During STS Viewing Experiments

ATA

RECOMMENDATION

- ATA and Rockwell Recommend Proceeding to Phase II
  - Phase I Objectives Have Been Achieved
  - Requirements Clear
  - Design Concept Meets Requirements
  - Innovative Advances Solve the Key Problems of Manned Space Observation